Inland Navigation Simulation Model: Verification and Evaluation

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The inland navigation simulation model is part of the methods and models developed by the Office of the Chief of Engineers to assist the U.S. Army Corps of Engineers in efficiently and effectively managing the inland waterway system. The model is used to evaluate system performance under current or proposed conditions. Verification and evaluation were critical tasks in establishing a basis for confidence in the model results. The testing effort focused on four areas: (a) determination of steady-state conditions, (b) minimization of the effects of randomness, (c) sensitivity analysis of key input parameters, and (d) historical comparison. Three versions of the model were tested. Each subsequent version incorporated more explicit representation of various navigation lockage activities and corrected deficiencies found in earlier versions. The preliminary findings of the Corps of Engineers evaluation study indicate that the model performs satisfactorily. However, the degree of accuracy in applying the model to specific navigation studies will depend heavily on the quality of data, the input specifications, and the computer and human resources assigned to the task.

The inland navigation simulation model is part of the methods and models developed by the Task Group for Inland Waterways Systems Analysis of the Office of the Chief of Engineers, U.S. Army Corps of Engineers. These tools assist the Corps of Engineers to achieve their goals in the area of navigation, which are (a) to operate the current inland waterway system as efficiently as possible and (b) to select the best size, location, and timing of inland waterway improvements.

The inland navigation simulation model fits within the waterway network analysis phase of the comprehensive methodology of waterway systems analysis. As part of the interrelated activities of demand and modal-split analysis, it quantitatively assists in the evaluation of system performance for planning, project studies, and operations analysis.

Although simulation techniques for the analysis of navigation facilities have been developing over the past 15 years, most of the earlier models were developed for special studies. The inland navigation simulation model was developed to handle analysis of a large-scale navigation network, including the entire inland waterway system of the United States.

Incorporating the necessary flexibility in the model was a complex task. The verification and evaluation efforts, which have involved extensive data collection and the development of support programs to organize input and analyze output, have also been formidable. Verification established a basis for confidence in the results that the model will generate under future conditions. Evaluation determined the situations to which the model can best be applied and also revealed its limitations. This paper deals primarily with the verification and evaluation efforts of the Navigation Studies Staff of the Pittsburgh District, U.S. Army Corps of Engineers, for the Office of the Chief of Engineers.

DESCRIPTION OF THE MODEL

The inland navigation simulation model is a generalized model that provides explicit representations of individual waterway facilities, cargo consignments, and vessels. Figure 1 shows the major elements of model input and output. The size of problem that the model can handle is limited only by the computer resources available. There are no inherent restrictions on the number of ports, locks, river segments and tributaries, towboats, barges, types of towboats and barges, or commodities. The model was specifically designed to accommodate systems at least as large as the entire Mississippi River-Gulf Coast waterway system.

Inland waterways are represented in the model as a network of interconnected links and nodes. Contiguous link-node groups are organized into sectors. Nodes represent the locations of ports, locks, junction points, and sector boundaries, and links represent river segments between nodes. Figures 2 and 3 show the general network and sector components. The effects of specific channel conditions, such as bends or shoals, are normally represented implicitly by their constraining effects on navigation. Special channel conditions can, however, be explicitly represented. Each lock facility is explicitly represented in the form of tow-processing time distributions for each chamber. Processing time is broken down into approach, entry, chambering, and exit times in a manner compatible with historical data. Single, setover, multiple-cut, multiple-vessel, and open-pass lockages are all accommodated. Other waterway facilities such as bridges, piers, and navigation aids are represented implicitly through their effects on tow size and speed. Linear stretches of docks are combined and abstracted as a single point at which cargo originates and terminates. Port processing is represented by loading and unloading times and by pickup and drop-off times.

Commodity movements enter the model in the form of a list of individual shipments characterized by commodity type, origin port, destination port, tonnage, and earliest possible departure time. This list is created either by a separate interface program that operates on a port-to-port, origin-destination tonnage matrix or through specific waterway demand analysis studies.

Individual towboats are explicitly represented and described by identification number, power, size, maximum permissible flotilla size, and sectors where they may operate. Barges in tow are represented as barge groups that consist of one or more barges with common characteristics. All types of towboats and barges are permitted, including dedicated equipment. Origin-destination movements through the waterway network are explicitly represented. Tow makeup (allocation of shipments to barges and barge groups to towboats) is internal to the model. En route drop-off and pickup of barges are permitted, and fleeting operations are represented. Empty-barge movements needed to accommodate trade imbalances are scheduled internally by means of decision rules built into the program. Recreation vessels are individually represented in terms of arrival at a lock for lock processing, but trip connectivity is not represented. Weekend and weekday arrival rates are specified by the user.

MODEL VERIFICATION

Data collection and model testing, modification, and evaluation were all required to determine the validity of the model. Various existing data sources were used, including (a) physical characteristics of inland waterways, navigation charts, and performance monitoring system (PSM) data of the Corps of Engineers; (b) histor-

ical commodity flow data of the Waterborne Commerce Statistics Center (WCSC); and (c) vessel data and regulations of the U.S. Coast Guard. These sources provided sufficient information for model testing; however, in application of the model, field studies were recommended for the forecasting of future demand, fleet composition, and port operations.

Four series of tests were performed to evaluate the capability and accuracy of the model. The purpose of the first test was to determine the amount of simulation time required to reach stable, or steady-state, conditions. The simulation model randomly allocates towboat and barge equipment to ports in the system by a preliminary scan of the shipment file. At the point at which equipment utilization became stable and all originating tonnage was shipped during the desired time interval, the system was defined as having reached a steady state.

Tests were then made to ensure that the effects of randomness caused by the use of probability distributions in various system operations were minimal. Several model runs were made by using different initial random number seeds (within the conditions specified for the pseudorandom number generator used in SIMSCRIPT II.5) to analyze this effect.

The third set of model tests performed a sensitivity analysis of several key input parameters. The tests included altering the amount and types of towing equipment, the timing of shipments, shipment sizes, physical lock characteristics and components of lockage time, port handling operations, and waterway channel characteristics such as channel depths and velocities. The sensitivity analysis checked model logic against known or intuitive system responses. It also revealed the importance of various input parameters and provided insight into where the greatest effort should be made in future data collection studies.

Finally, and most important, model output was statistically compared with known system conditions for a selected historical time period. The desired response was to reproduce historical lock operations at a 95 percent level of confidence. The time period selected was September 1976. Variables analyzed during these tests included lock utilization; average tonnage per tow, barges per tow, delay per tow, service time, queue length, and lockages by type and chamber; and total tonnage and tows and barges by chamber and direction for the entire simulated time period.

The model tests described generated a large volume of output for analysis. Several support programs were developed to expedite the process of verification. The most important of these programs statistically compared simulation model output with historical data. The program, named ANALYS, was developed by the North Central Division of the Corps of Engineers. The method of batch means is used by the program to eliminate autocorrelation in simulation and historical time-series data. An analysis of variance is performed with the classical t- and f-tests. The output of ANALYS provides for each variable and batch count and mean and standard deviation values for each data series in the two input files (historical and simulation), the calculated t-statistic and f-statistic, and level-of-significance factors. This information was used to determine which test was applicable and to construct the confidence level achieved by the model output. The ANALYS processor was also used to compare model output from sequential time periods. This comparison checked the significance level of the randomness effect and assisted in determining stable system conditions achieved during any model run.

Figure 1. Primary input and output for inland navigation simulation model.

Figure 2. Typical network representation.

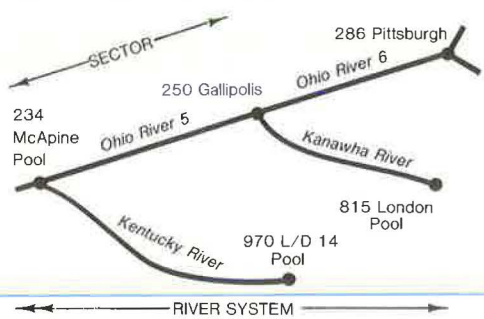
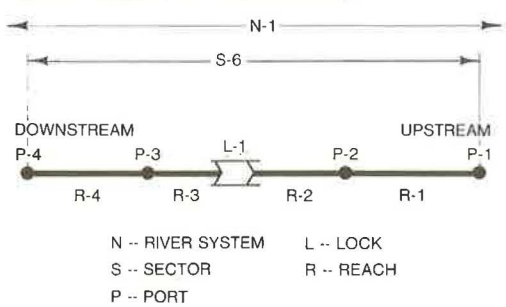


Figure 3. Typical sector representation.



EVALUATION OF MODEL TESTS

During the first phase of the development of the Corps of Engineers inland navigation systems analysis (INSA) model, system and shipment data files were prepared to include all of the U.S. inland waterway system. This scale represented the maximum network size the model would be required to handle. Model verification and evaluation with the maximum size of system would have been impractical from both a time and cost standpoint. The network scale was reduced to approximately one-fifth the size of the original model. The test network included the Ohio River main stem and the Monongahela, Allegheny, and Kanawha tributaries in detail; the remaining system was abstracted to a few major shipping and receiving areas. Elements of the network included eight river systems, 29 river sectors, 125 ports, 42 locks, nine commodity classes and groups, 27 towboat classes with 482 towboats, and seven barge classes with 12 860 barges. The reduced network scale adequately served the needs of model verification and saved considerable staff and computer time over the number of model runs required for each iteration of the testing effort.

Three versions of the model have been tested to date. They are identified as SIMGO, SIMGO2, and SIMGO3. Based on the inadequate results of tests with SIMGO, logic changes were made to the handling of the movements of empty towboats (lightboats). The modification ensured that only one towboat would be flagged to pick up a shipment and that a towboat would not travel light for

Figure 4. Lock utilization versus simulation time.

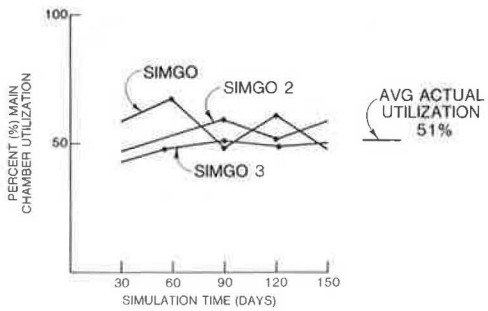


Figure 5. Average lock tonnage versus simulation time.

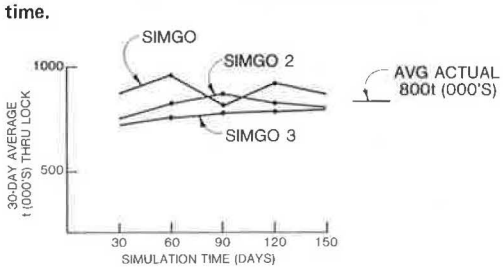
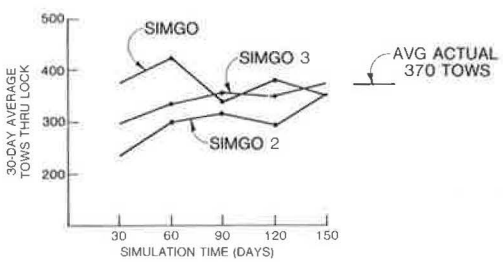


Figure 6. Average number of tows versus simulation time.



an unreasonable distance to pick up a shipment. In addition, if a shipment was picked up by a passing tow earlier, the assigned lightboat would be released to pick up another shipment. Along with this modification, the input was reviewed and updated with the results of recent detailed studies of the current Corps of Engineers PMS and WCSC data.

SIMGO2 performed substantially better in the model test but was not adequate in the historical comparison. At this point, several additional capabilities were recognized as desirable. As a result, SIMGO3 was developed. SIMGO3 incorporates a modified logic for determination of lockage type. The procedure used by SIMGO and SIMGO2 versions is based on the relative surface areas of tow and chamber. Basically, the ratio R of the total deck area of the tow to the area of the lock chamber was computed, and the corresponding type of lockage was looked up in a user input table. Over a specified range of R, a choice between straight single and setover was made randomly according to given probabilities. The principal drawback of using areas was that the chamber capacity could be overestimated in cases in which barges do not pack efficiently into a chamber. The resulting problem was particularly dominant at smaller or odd-sized older locks in the system. However, the method was originally chosen to save the extensive computer time and storage requirements that would be necessary to handle a direct packing algorithm. A revised computational method was developed. In most cases, this modification improved the accuracy of the determination of type of lockage.

There was also a desire for a more flexible policy of chamber selection in the model. The logic originally incorporated in the model for selection of a chamber at a multichamber lock facility was strongly biased toward the use of a main chamber. This policy appeared to reflect actual operations at many locks but, at highly congested locks and locks where both chambers were of the same size, it was less realistic.

In adapting the model for specific project studies, SIMGO3 modifications included additional lockage operating policies, particularly for the analysis of nonstructural alternatives. Originally, the model permitted priority policies of "first come, first served" and "up and down" to be specified. Among the other policies that are now available are (a) ready to serve, (b) queue balance (i.e., the first tow in the longer queue would be chosen), (c) hours up, hours down (upbound tows served for a fixed period of time and then downbound tows served for another, possibly unequal, period), and (d) commodity priority, which takes into account the value of the commodities being shipped. SIMGO3 provided the most successful results for the historical comparison tests.

All test results could not be covered in this paper. The most important results are summarized in Figures 4-6 for a typical lock in the system. Figure 4 compares use of a main-chamber lock for various lengths of continuous simulation time for the three model versions with average actual utilization for the September 1976 period. The results of SIMGO indicated that the system did not attain a steady-state condition. SIMGO2 improved the run condition, and SIMGO3 indicated that the system stabilizes after 60 days of simulation warm-up time. The stabilized period fell below average actual utilization for September 1976. However, examination of the total tonnage, tows, and types of lockages that occurred similarly varied between actual and simulated. The variance was not determined to be significant in this case.

The variation in results is shown in Figures 5 and 6. The fluctuations in utilization, tonnage, and tows were a result of long waits for towboats and barges at ports. This problem was reduced by modifying the model logic and restructuring the towboat and barge input data to more realistically represent existing operating areas. This prevented concentrations of equipment in areas that were distant from shipment demands.

A typical set of results for the historical comparison test is given below (1 t = 1.1 tons):

Variable	Actual (September 1976)	Simulation (SIMGO3)
Utilization (%)	61	66
Tonnage	2 025 450	1 602 700
Total tows	808	797
Total barges	2185	2291
Average tow size (barges per tow)	2.7	2.9
Average delay per hour (%)	0.5	0.8
Total lockages	859	919

Because SIMGO and SIMGO2 did not stabilize, SIMGO3 provided the only valid simulation model results for comparison with the historical data. Average tow size, number of lockages, and distribution of lockage types are comparable. Average delay and queue vary, but these variables are highly dependent on an arrival pattern. The historical arrival pattern was not explicitly represented in the model but was implicitly represented in the timing of commodity movements within the shipment file.

Although the model has essentially been verified, its

limitations must be recognized. The modifications made to develop SIMGO3 are relatively minor in view of the overall task of developing the initial simulation model. They have increased the flexibility of the model to handle a wider range of navigation project studies at various depths of detail. However, this increased flexibility has added significantly to the cost of operating the model. The most direct cost is computer resources. Simulation programs are notoriously heavy users of computer time, and representational inefficiencies are magnified by the commonly specified requirement that series of runs be made under varying conditions, often by replicating individual runs to obtain statistical validity. Increased computer costs are not the only burden of increased detail. Frequently, the level of detail has been and is limited by the availability of data or simply by a lack of detailed knowledge of how the system actually works. The latter factor was particularly prominent where human decisions were involved. The dispatching of towboats in the waterway system was a prime example.

Selecting the optimum level of detail was and will be largely a matter of judgment based on the particular navigation study being undertaken. Recent validation tests have given only a general idea of the adequacy of the representation and analytical complexity of the model for the Ohio River system scale.

CONCLUSIONS

The inland navigation simulation model represents a key part of the systems analysis required for the navigation planning efforts of the Corps of Engineers. In conjunction with commodity flow and modal-split analysis, the simulation model provides, through network analysis, insight into system reactions to proposed changes. The verification and evaluation phase was most important in developing confidence in model results under new conditions.

Data collection and model testing and calibration for this large-scale simulation were extensive. There cannot be enough emphasis put on the importance of good input data. As with all types of computer modeling efforts, the "garbage in, garbage out" principle holds true here. The success of the historical comparison tests was largely dependent on the extensive data collection and analysis efforts. For each potential application of the model, the amount of detail desired will have to be balanced with the economic feasibility of data collection and computer resource limitations. In addition, in this context the degree of confidence desired is directly related to the effort required in specific model formulation. Trade-offs may be necessary to meet budgetary and time constraints in the application of the inland navigation simulation model to ongoing and future navigation program and project planning studies.

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Method for Estimating Nonphysical, Transportation-Related Business Losses Caused by Flooding on the Inland River System

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Research undertaken to develop and document a methodology for the estimation of secondary transportation-related flood losses to commercial and industrial firms is reported. The categories of loss estimated exclude physical damage, which is already included in current methodologies. The methodology categorizes transportation-related flood losses into three broad areas. The first area is losses in travel time and travel cost—estimated costs of additional route circuity and travel time, primarily for the movement of freight. The second area is that of business interruption losses, which relate to transportation in the sense that access is essential to the functioning of businesses. The third area of loss is consequences of flood conditions that are not measured solely in dollars. Typical of this category might be increases in energy consumption or air pollution as a result of flood conditions.

The objective of the research reported in this paper on the development of a methodology for the estimation of transportation-related flood losses is to describe the estimation problem, present alternative methodological approaches, and select an approach for further development. Before this work was undertaken, the estimation process for assessing transportation-related flood losses was restricted to direct physical losses. These include rehabilitation or replacement of roadways and bridges as well as property-damage losses for commercial and industrial establishments. These estimates have been based on postflood surveys of many sites.

The research described here develops an estimation methodology for other types of transportation-related flood losses, which can be categorized into three broad areas. The first of these is losses in travel time and travel cost. These are estimable costs of additional route circuity and travel time, primarily for the movement of freight. The second area is that of business interruption costs, which relate to transportation because access is essential to the functioning of businesses. The third area is consequences of flood conditions that are